FEATURE

Glass & carbon fiber reinforcement combine in hybrid long fiber thermoplastic composites to bridge price & performance gap

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Fiber reinforced materials have expanded use of thermoplastics into semi-structural applications where their mechanical properties provide the performance needed to displace traditional materials. In this arena, glass fiber has long been the workhorse reinforcement of choice because it significantly increases polymer stiffness and strength performance with favorable economics. Interest in carbon fiber to reinforce thermoplastics has recently grown due to its ability to provide even more robust mechanical properties along with reduced weight; however, that performance comes at a cost that prices carbon fiber out of the reach of many applications.

For components produced using injection molding processing techniques, long fiber reinforced thermoplastic composites represent the pinnacle of mechanical performance available in flowable materials. The 12 mm long filaments of fiber reinforcement in long fiber composites provide a trifecta of capabilities that can't be obtained in unison using other types of particulate media as a method for reinforcing plastics.

First, as with other reinforcements, modulus of plastic compounds increases in proportion to the long fiber content loading as the stiffer fiber additive lends this characteristic to the matrix polymer with which it's compounded. Second, strength rises to higher levels than with other reinforcements as longer segments of fiber have a higher aspect ratio with more surface area in contact with the polymer. Added length facilitates better transfer of stress forces from the polymer to the stronger fiber reinforcement improving load carrying ability. Lastly, boosts in durability occur as longer fiber segments intertwine to form an internal structural skeleton of fiber that promotes dissipation of impact forces throughout components instead of being localized in one area. High impact resistance in a stiff material is a fundamental reason for choosing long fiber composites over other types of reinforced plastics.

In metal replacement applications that have structural performance requirements, long glass fiber reinforced thermoplastic composites have become the go to material of choice. In fact, long glass fiber reinforced polypropylene has become commoditized by its extensive use in the automotive industry where it's widely used as a lightweight substitute for metal components. There, the use of long glass fiber composites has reduced vehicle cost and weight, with weight savings prized for its ability to increase fuel economy and reduce emissions to meet increasing regulatory targets.

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Carbon fiber has earned a reputation as being a 'high tech' material reinforcement through its extensive use in aerospace and sporting goods industries where it provides metal-like performance at a fraction of the weight. In industries where weight reduction is a Holy Grail pursuit, the higher cost of carbon fiber can more easily be justified for the lower mass and performance gains it offers over other methods of reinforcing plastics.

In other industries, using a reinforcement that increases material cost fivefold or more without a corresponding increase in mechanical performance is difficult to rationalize. In an effort to lower the cost to entry barrier for adopting carbon fiber, long fiber compounder PlastiComp, Inc. of Winona, MN, in the U.S. has developed a product line of hybrid long fiber composites that combine long glass fiber and long carbon fiber together in a single, ready-to-mold composite pellet.

Early experimental trials showed that combining these two fiber types together created unique performance synergies that could not be achieved using either fiber type by itself. Including long glass fiber reinforcement boosted durability beyond the range obtainable with long carbon fiber alone. Additionally, adding long carbon fiber reinforcement increased stiffness and strength to higher values than long glass fiber could achieve. Most importantly, a hybrid material that contained lower levels of long carbon fiber reinforcement would be significantly less expensive than all-carbon long fiber reinforced composites (Fig. 1).

PlastiComp combines continuous filaments of glass and carbon fiber together in a unified composite pellet to simplify processing and provide better performance. While separate long glass fiber and long carbon fiber composite pellets can be post blended together, their density differences can result in separation during material handling affecting dispersion uniformity. Metering separate composite pellets at the injection molding press adds a layer of complexity and obtaining a homogenous mix can lead to fiber length attrition that negatively impacts composite performance.

To obtain maximum composite performance, long fiber materials require processing in a manner that minimizes shear during the melt phase with the screw of the injection mold press and in the flow path of the runner and gate system inside the mold tooling. Improperly processing long fiber composites produces shorter mean fiber length, which results in reduced strength and durability of molded articles.

Hybrid long fiber composites with glass and carbon fiber reinforcement expand the performance range of long fiber materials available to product designers and material engineers with a vast number of fiber reinforcement combinations possible to balance material cost and performance requirements. Instead of having just all-glass or all-carbon long fiber composites to choose from, the capabilities of long fiber materials now become truly tailorable.

Long fiber-reinforced hybrids are the ideal material for applications whose performance requirements are beyond the reach of long glass fiber reinforced composites and those that could take advantage of the higher performance carbon fiber provides but are to price sensitive to absorb the higher material cost.

An example of how a hybrid long glass and carbon fiber composite can bridge the performance and price gap that exists between long glass fiber and long carbon fiber products can be easily explained by comparing the mechanical properties of a 40% long fiber hybrid polyamide 6/6 with equivalent 40% long all-glass fiber and 40% long all-carbon materials.

A 40% hybrid long fiber combination of 20% long glass fiber and 20% long carbon fiber has a flexural modulus of 17,930 MPa, which is 13% lower than an all-carbon long fiber variant and 86% higher than an all-glass long fiber product. A tensile strength value of 248 MPa for the hybrid composite is 4% below an equivalent all-carbon material and 24% higher than an all-glass product.

Since the hybrid composite contains half as much carbon fiber as the all-carbon material, its cost is 30% less but it is able to provide 87% of the costlier material's stiffness and 96% of its strength. On the durability side, the inclusion of long glass fiber boosts the hybrid composite's un-notched impact resistance to 1004 J/m which is a 25% improvement over a proportional long

FIGURE 1

12 mm long hybrid long glass and carbon fiber composite pellets.

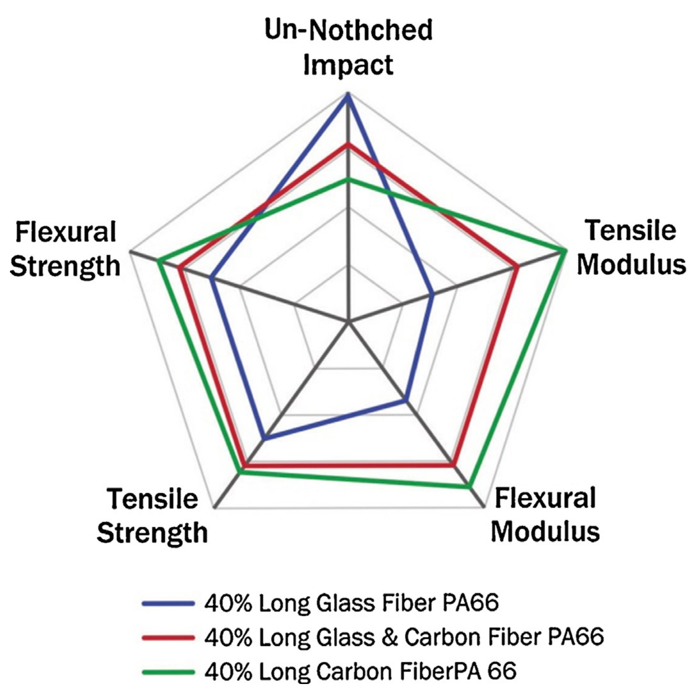

FIGURE 2

A hybrid combination of long glass and carbon fiber provides performance similar to an all-carbon fiber composite at a significantly lower cost.

all-carbon fiber product and 22% less than a similar long all-glass fiber material (Fig. 2).

	40% long glass fiber PA 6/6	Δ_1	Hybrid 40% long glass & carbon fiber PA 6/6	Δ_2	40% long carbon fiber PA 6/6
Cost Multiplier	1.0	–	3.3	–	4.9
Density	1.45	−3%	1.40	+7%	1.31
Tensile Modulus	11730 MPa	+106%	24140 MPa	−22%	31040 MPa
Flexural Modulus	9660 MPa	+86%	17930 MPa	−13%	20690 MPa
Tensile Strength	230 MPa	+24%	284 MPa	−4%	297 MPa
Flexural Strength	328 MPa	+24%	405 MPa	−11%	455 MPa
Un-notched Impact	1280 J/m	−22%	1004 J/m	+25%	801 J/m

Δ_1 performance change between long glass fiber and hybrid long fiber composites.
Δ_2 performance change between hybrid long fiber and long carbon fiber composites.

The mechanical properties of hybrid long fiber reinforced composites land in the performance 'sweet spot' that a lot of applications require to consider converting them from metal to reinforced thermoplastics, but are able to achieve that performance at a more affordable price point than all-carbon fiber reinforced materials.

The availability of more affordable high performance thermoplastic composites will facilitate additional metal to plastic conversions. Most of the simple applications that easily benefited from conversion to plastic from metal have already been accomplished with long glass fiber composites. Engineers are seeking materials or processes that give them a more cost effective way to adopt carbon fiber's higher performance and the tailorable nature of long glass and carbon fiber hybrids provide exactly the stepping stone approach they need.

If someone is looking at long carbon fiber reinforcement for its stiffness and strength but disappointed because the impact resistance isn't quite what they need, then adding long glass fiber to the composite in the form of a hybrid material can give them the durability boost they require. The inverse is also true, if long glass fiber reinforced composites can't provide the stiffness or strength needed to successfully carry a load then adding long carbon fiber to the mix can improve performance to the desired level.

A sporting goods application has already been commercialized using PlastiComp's hybrid approach of combining long glass and carbon fiber reinforcement. The customer was looking for a way to eliminate a metal insert to create an easier to manufacture, purely injection moldable version of their product, but all-glass long fiber materials couldn't provide enough stiffness. Their other option normally would have been to use an all-carbon long fiber composite to achieve the necessary modulus boost; however, that options higher price point would have made their product cost prohibitive. Instead, a hybrid solution provided the necessary stiffness performance at a price point that proved successful and allowed them to take an all-plastic version of their product to market where it has received much acclaim.

The prestige carbon fiber has in the minds of many consumers for delivering superior performance affords products incorporating it additional perceived quality and value that allows them to demand a price premium over similar products made from simpler plastic materials. Embracing the concept of using carbon fiber to add value to products gives long glass and carbon fiber hybrids a unique position in developing and promoting applications in many market segments such as consumer items and sporting goods.

Including even low levels of carbon fiber creates a legitimate carbon fiber composite that can provide a distinct marketing advantage to upsell or differentiate a product from competitors. The rational for deploying carbon fiber doesn't always have to be obtaining better mechanical performance. Long fiber hybrids tailorable ability to adopt carbon fiber using a stepped approach to control cost allows its use in mid-range applications that otherwise would be priced out of deploying carbon fiber composites.

In hybrid long fiber formulations, carbon fiber can be combined with glass fiber in multiple ratios to any total fiber weight percent loading up to 50%. Best economies are obtained with lower loading levels of long carbon fiber reinforcement where its combination with long glass fiber provides a higher level of performance unobtainable in all-carbon long fiber composites with the same carbon fiber loading percentage.

Since long carbon fiber is typically the most expensive component in composites with which it's incorporated, including long glass fiber as a synergistic additive has virtually no impact on composite cost. In fact, depending on the cost of the thermoplastic polymer matrix with which it's combined, adding long glass fiber may actually decrease the total cost of the composite if it displaces a more expensive plastic polymer. The manufacturing cost for compounding long fiber and thermoplastic polymer into a composite via pultrusion is essentially the same regardless of the amount of long fiber in the product.

Currently, PlastiComp has its single pellet hybrid long glass and carbon fiber composites available in polypropylene, polyamide, and engineered thermoplastic polyurethane polymers with the long glass fiber and long carbon fiber mix ratio customizable to application requirements. Long fiber reinforcement is compatible with any thermoplastic and hybrid fiber solutions are possible in other thermoplastic polymer matrices as application demand develops.

For those desiring to adopt carbon fiber primarily for its weight reduction characteristics compared to glass fiber, hybrid long fiber solutions might not be the best solution. Although any long fiber reinforced thermoplastic composite is going to provide significant weight saving over traditional metal materials, due to long fiber hybrids use of glass fiber they are going to have densities just slightly less than similar long glass fiber products.

Additionally, due to the inclusion of carbon fiber and that ingredients cost, hybrid long glass and carbon fiber composites are not likely to be strong replacement material candidates for existing long glass fiber applications unless those components are experiencing failure due to material performance limitations.